Design and Implementation of Persuasive Public Wi-Fi to Derive Prosocial Network Usage

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***Abstract*—As the high-speed wireless network spreads, the usage of shared Wi-Fi in places such as offices, coworking spaces, and homes has been increased. Along with the development and diversification of digital content, the amount of data consumed by individual devices has also grown. In situations where multiple users share limited network resources, some content that consumes a large amount of bandwidth like video streaming can potentially degrade the Quality of Experience (QoE) for other users nearby. Consequently, a need for persuasive intervention systems that encourage prosocial behavior is rising taking into consideration the QoE of other network users. To address this issue, this study proposes a "Persuasive Public Wi-Fi" that employs Wi-Fi to incrementally convince users towards more considerate usage of network resources. To be specific, we suppose that the persuasive public Wi-Fi must include three different modes: 1) a mode of normal networking, 2) a mode that can intervene with individual users through a captive portal, and 3) a mode that intentionally limits bandwidth, i.e., Quality of Service (QoS) control. This work demonstrates the design and implementation of the proposed system and presents the results of operational verification using a prototype system.**

***Index Terms*—Public Wi-Fi, Prosocial Behavior, QoE, QoS Control, Captive Portal**

I. Introduction

As the high-speed wireless network spreads, the enjoyment of diverse ICT services has been enabled leading to the situations in which numbers of people are routinely using digital devices. With this trend, the environment for internet access has been improved with an increase of Wi-Fi usage provided by shared spaces such as offices, coworking spaces, and homes, thus enhancing user convenience. Concurrently, the diversification of digital content such as streaming services, high-resolution videos, and online gaming requires unprecedented wide bandwidth. As a result, the amount of data consumption by individual devices has increased dramatically, necessitating a corresponding increase in the communication bandwidth required.

However, the sharing of limited network resources among multiple users means that when one user consumes a large amount of bandwidth for content such as video streaming, it can potentially degrade the QoE for other users. Furthermore, some service providers for social networking or video streaming intentionally design addictive content to capture and retain the continuous interest and attention of users, making it difficult for users to stop their service based on willpower and self-control [1] [2]. Therefore, we suppose that there is a high demand for persuasive intervention systems that encourage prosocial behavior, considering the QoE of other network users.

In recent years, some applications have been reported about encouraging self-regulation in the use of digital devices, such as those that manage and limit application usage time, known as "screen time," and those that temporarily restrict app notifications [3] [4]. These tools can be functioned on personal devices, but it is difficult to simultaneously impose restrictions across multiple devices.

Therefore, we utilize the Wi-Fi that can access and control the multiple devices connected to its network, as our proposed approach. Current Wi-Fi is equipped with URL filters that restrict access to specific websites and QoS algorithms that prioritize traffic for certain applications. However, URL filter allows only two options of either completely restricting access into specific sites only or not restricting them at all, which is a compulsory intervention. Consequently, in some places where free internet use is encouraged like public facilities or cafes, we may need not a forceful intervention, but a phased persuasive intervention that promotes prosocial behavior, with remaining the user's own choice. In addition, since QoS can only be statically configured, it does not always guarantee an appropriate and balanced setup for a given environment. For this reason, the function that dynamically changes QoS settings is necessary in accordance with the environmental context.

In response to the challenge of certain users' excessive digital content consumption that severely degrades the overall QoE of a network, this study has designed and developed a "Persuasive Public Wi-Fi." Our system is designed to incrementally persuade users towards prosocial behavior that considers the QoE of the other users. Our proposed system contains three different modes: (1) a high-speed communication mode, (2) an intervention mode that engages individual users through a captive portal, and (3) a QoS control mode that deliberately impairs a user's QoE by restricting their bandwidth usage. Our system is designed to dynamically switch between these modes, adapting to the user's current context. The implementation is completed by constructing two guest operating systems on a virtual machine—one equipped with captive portal functionality and the other with QoS features—both of which are managed by a central host operating system to enable seamless mode transitions. This prosocial behavior induced by persuasive intervention conducts through the user's decision making. Therefore, it can reconstruct the user's behavioral standards, and as a result, it is expected that

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the user will be able to consistently make better choices.

In this paper, Section 2 describes related work in the context of this study, Section 3 outlines the assumed environment and system requirements of the system proposed herein, Section 4 details the configuration of the proposed system and the results of its operational verification, and finally, Section 5 concludes the paper.

II. Related Work

A. Adaptive QoS

Many studies on QoS and QoE have been presented. Liu et al. have proposed more accurate QoS prediction schemes in Mobile Edge Computing (MEC) by considering user-related and service-related contextual factors, enabling an improvement in user satisfaction [5]. Rao et al. have elucidated the relationship between QoS and QoE in the context of video conferencing, revealing a preference among users for high and stable bandwidth [6]. Xiaolan et al. have proposed an adaptive QoS-aware congestion control framework utilizing machine learning for live streaming with Multipath TCP (MPTCP) to meet diverse QoS requirements [7]. Bo et al. achieved a reduction in energy consumption and maintenance of system performance in 5G cellular networks by switching QoS levels according to requirements [8]. However, existing studies focus on optimizing QoS or enhancing QoE as an approach to make the use of digital contents more comfortable. Therefore, it has not been yet clarified whether intentionally lowering QoE can effectively deter the unnecessary use of digital content.

B. Digital Wellbeing Support

In recent years, many studies have reported on limiting the unnecessary use of digital content. For example, an app that locks the app once the user exceeds the defined daily usage time limit [9] and an app that sets a usage barrier requiring a 30-digit input to launch [10] have been proposed. Furthermore, there are methods that intentionally impair the appeal due to visual effects by turning smartphones to gray-scaling, thus reducing the content usage experience [11] [12]. Additionally, our research group has developed Color-wall, which turns the display to gray-scaling user launched visually seductive and addictive digital contents [13]. However, a challenge with these prior studies on Digital Distraction is that, even if restrictions are placed on the devices, content can still be accessed using devices where the apps are not installed, indicating a lack of multi-device support. Existing DSCTs (Digital Self-Control Tools) are seldom adaptable to multi-devices, which is mentioned as a future issue [14]. Therefore, systems that can suppress the unnecessary use of digital content on multi-devices are needed.

This study aims to clarify to what extent dynamic QoS/QoE, depending on the user's context, can be effective in suppressing the use of digital content, a question not yet addressed in previous research. Furthermore, the study will also examine efficient intervention control methods in a multi-device environment using Wi-Fi.

III. Proposed System

In this section, we describe our scenario and system requirements in the proposed system.

A. Definition of prosocial behavior we assume

Prosocial behavior is behavior that benefits others or groups of people voluntarily without the expectation of rewards. In the usage of shared Wi-Fi, there is a concern that the overall network QoE significantly degrades when a user consumes digital content requiring wide bandwidth. Therefore, in this study, prosocial behavior is defined as the action of such users who consider the QoE of other network users and suspend their use of digital content. As a result, network resources are distributed efficiently and the QoE of the entire network is improved.

B. Scenario

In this study, we assume that the proposed system is operated in shared places such as offices, coworking spaces, and cafes. We describe a scenario illustrating how the Persuasive Public Wi-Fi promotes prosocial behavior toward users.

Firstly, assuming that there is user A at an office, who has abandoned his work to enjoy digital content that using too much resources. User A's activity monopolizes the limited network resources, significantly reducing the internet speed for other users, leading to decreasing people's QoE. At this point, the system detects the content being used by user A, and recognizes that he consuming a considerable amount of bandwidth, then displays a warning on user A's device advising them to discontinue their contents. However, user A is engaged in the content and ignoring the warning, and continues his inconsiderate and further causing a decrease of internet speed and QoE for other users. Consequently, the system judges that user A continues to use the content and then restricts the bandwidth further to intentionally provide a lower QoE. As a result, the internet speed for other users' devices improves, restoring an environment that can provide a better QoE. User A, experiencing the reduced QoE and unable to comfortably use the content, decides to stop their use of the content and resumes the work they were originally supposed to do in the office.

C. System Requirements

This section describes the system requirements for solving the problems in the scenario.

- **Gradual Intervention through Context Awareness**
  In this study, context awareness refers to the immediate recognition of a user's digital content usage and the persuasive intervention based on this information. Therefore, to accurately identify the digital content being used by users on the network in real-time, an analysis on the application level is required. Then, based on the analyzed user context, it is necessary to consider an acceptable and effective intervention strategy. In this intervention strategy, the level of QoE provided should be appropriately adjusted depending on the user's context.

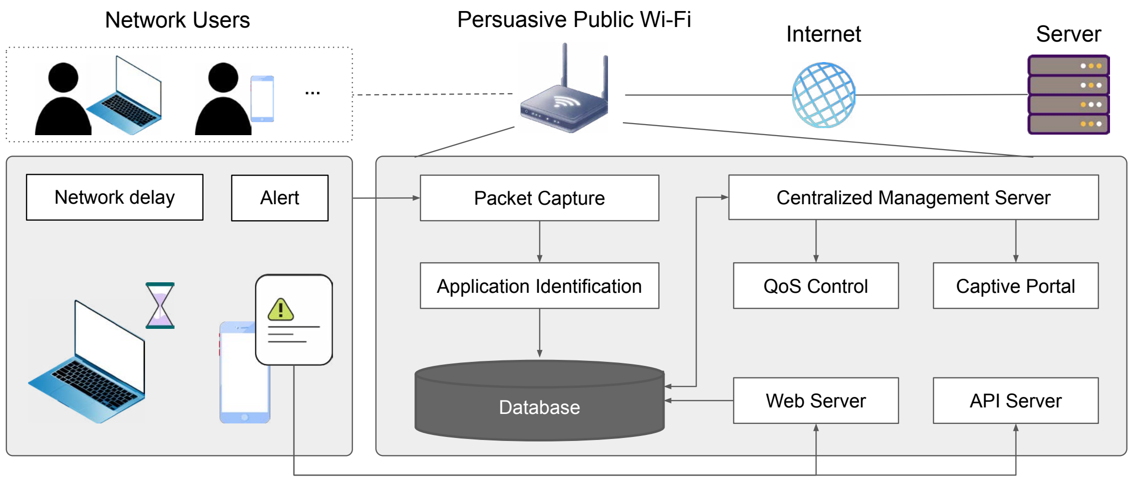


Fig. 1: Overview of Persuasive Public Wi-Fi

- **Promoting Self-awareness Using a Captive Portal** To limit digital content usage, context self-awareness is considered to be linked to the improvement of self-management. To intervene with network users in this way, a captive portal can be used to visualize and warn the usage status of content. However, normal captive portals are designed to provide promotional and other information to all network users after authentication and do not anticipate offering personalized feedback to individual users. Therefore, to separately intervene with individual users, tying the user's context with their device information enables intervention based on that user's context.
- **Access Restriction through QoS Control** If users cannot voluntarily improve their behavior through self-awareness prompted by the captive portal, a direct restriction on the digital content is necessary. Specifically, if the system determines that the use of digital content has prolonged and the overall network QoE keeps being degraded, or an individual's productivity has been lowered, the user's bandwidth is restricted through QoS control. This encourages the discontinuation of digital content usage and achieves a QoE improvement for the other network users.

D. System Design

The system design based on system requirements is described in Figure 1.

1) Identification of Digital Content: It is necessary to accurately identify the digital content consumed by users in real-time. Therefore, the system should be capable of capturing network packets in real-time and analyzing them at the application level. In our system, this is achieved by using Deep Packet Inspection (DPI). Also, the information of the identified digital content is stored in a database for each user-assigned private IP address. Persuasive intervention is implemented based on the information for each user obtained from this database.

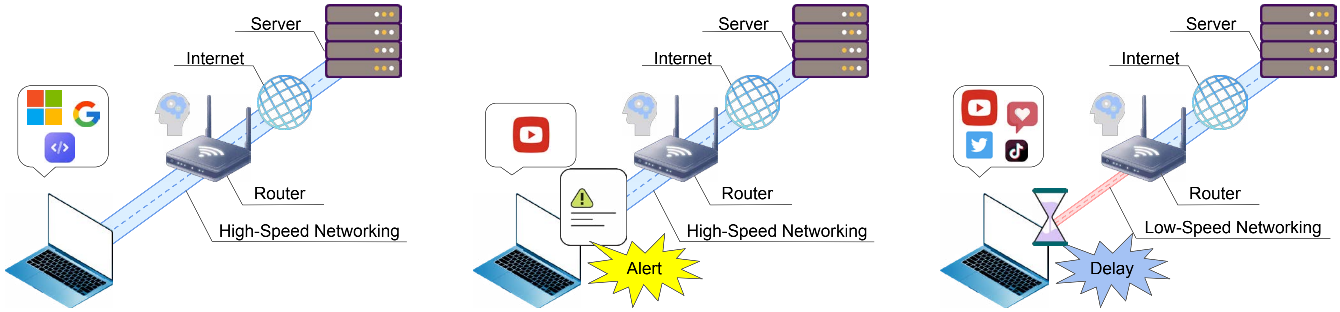
2) Intervention for Individual Users Using a Captive Portal: To display a warning screen after captive portal authentication, it is necessary to build a web server for the system. Furthermore, general used captive portals are designed to provide information such as promotions to all network users after authentication. To conduct interventions such as warnings for individual users, it would be considered to intervene based on the context information for each user stored in the system's database if the private IP address of the device can be obtained within the captive portal's browser. However, it is not possible to directly obtain the private IP address of a device from the browser due to Multicast Domain Name System (mDNS), which facilitates name resolution between devices on the same local network. Therefore, by implementing an API server in the system that returns the source IP address when accessing a specific port, the browser can obtain the private IP address. Additionally, the warning screen can be displayed at any time by dynamically managing authentication sessions.

3) Bandwidth Control through QoS Control: The system should contain a QoS control function to dynamically set user bandwidth. Moreover, it is possible to set the bandwidth for each user, allowing for individual interventions based on the user context information stored in the database.

4) Control of Gradual Interventions: Our system utilizes captive portal session management and QoS control to enable the Wi-Fi to perform gradual persuasive interventions. The dynamic changes in settings for these two functions are managed by centralized management server to maintain consistency in settings.

Through the coordinated operation of these components, the system provides the following three modes.

- **Mode 1** Mode 1 allows users to access the internet at a full speed without any interference from the system, which is shown in Figure 2a. Under this mode time, the system can continue to provide a high QoE, enabling an environment conducive to concentrating on their main tasks.



(a) Mode 1: Normal (b) Mode 2: Captive Portal (c) Mode 3: QoS Control

Fig. 2: Proposal Methods

- **Mode 2**
  Mode 2 utilizes a captive portal to display a warning screen that prompts users to interrupt their use of digital content, which is shown in Figure 2b. Specifically, when a user consuming content that degrades the overall network QoE is detected, the system can disconnect the user's device captive portal authentication session and force them to log in again, allowing the warning screen to be displayed at any desired time.
- **Mode 3**
  Mode 3 allows the intentional restriction of bandwidth through QoS control, which can reduce the user's QoE. Specifically, if users are not interrupted in their content usage in spite of warnings through the captive portal, the bandwidth can be forcibly limited to interrupt their content usage, which is shown in Figure 2c. This not only improves other users' QoE but also encourages them to return to their main tasks.

Through this three-mode system with gradual interventions, the Wi-Fi can persuade the discontinuation of the use of digital content that occupies bandwidth. The system allows network administrators to customize the settings optimally according to the context.

E. Operational Example of Persuasive Public Wi-Fi

As we described earlier, Persuasive Public Wi-Fi can persuade users through interventions using three modes. Here, we present a specific example of how Persuasive Public Wi-Fi operates on network users, as shown in Figure3.

As a precondition, Persuasive Public Wi-Fi is composed of four parts: capturing application usage, analysis for identifying applications consuming too much bandwidth, planning intervention method, and execution of the intervention.

Firstly, user A is using video streaming and social networking services (SNS), that occupy a significant amount of bandwidth (Figure 3 Phase 1). At this time, the communication speed of other devices connected to the same network is significantly reduced, leading to a decreased QoE. Consequently, Persuasive Public Wi-Fi detects the usage of bandwidth-intensive content and turns on the warning screen display function. As a result, the user device's captive portal session is disconnected, and starts reconnection, then a warning screen is displayed (Figure 3 Phase 2). However, if user A continues to use the content regardless of the warning screen, the warning display function is turned off, and the bandwidth restriction function is operated (Figure 3 Phase 3). As a result, user A's bandwidth is restricted, lowering his own QoE. On the contrary, the QoE of other users improves due to the restriction of user A's bandwidth. Additionally, user A feels the reduction in his QoE and interrupts their content usage. Then, The system turns off the bandwidth restriction function, resulting in an environment where all users on the network can concentrate on their main tasks with a high QoE (Figure 3 Phase 4).

IV. System Implementation and Operation

In this section, we represent the design and implementation of the system. this is constructed on Oracle Corporation's VirtualBox[1], a virtual machine provider. For the router providing the captive portal functionality, Pfsense[2], an open-source software firewall, was used. Also, Vyos[3], an open-source network OS, was used to perform the QoS control. These two operating systems are placed inside the virtual machine as guest OSes. As the captive portal feature of Pfsense includes the operation of a DHCP server, devices that need to display the captive portal must use DHCP distributed by Pfsense. Pfsense was placed on the WAN side within the virtual machine, and Vyos on the LAN side. In this setup, Vyos operates in bridge mode to enable the use of IP addresses distributed by Pfsense in the underlying network.

With such a network configuration, it is able to realize bandwidth limitations using a captive portal for warning and QoS control.

A. Detection of Utilized Services

The host OS and guest OS share a physical NIC (Network Interface Card), so packets from devices connected to the system can all be captured by the host OS. The packets passing through the router are monitored by the packet capture tool tcpdump, and the generated PCAP files are used to identify

[1]https://www.virtualbox.org/
[2]https://www.pfsense.org/
[3]https://vyos.io/

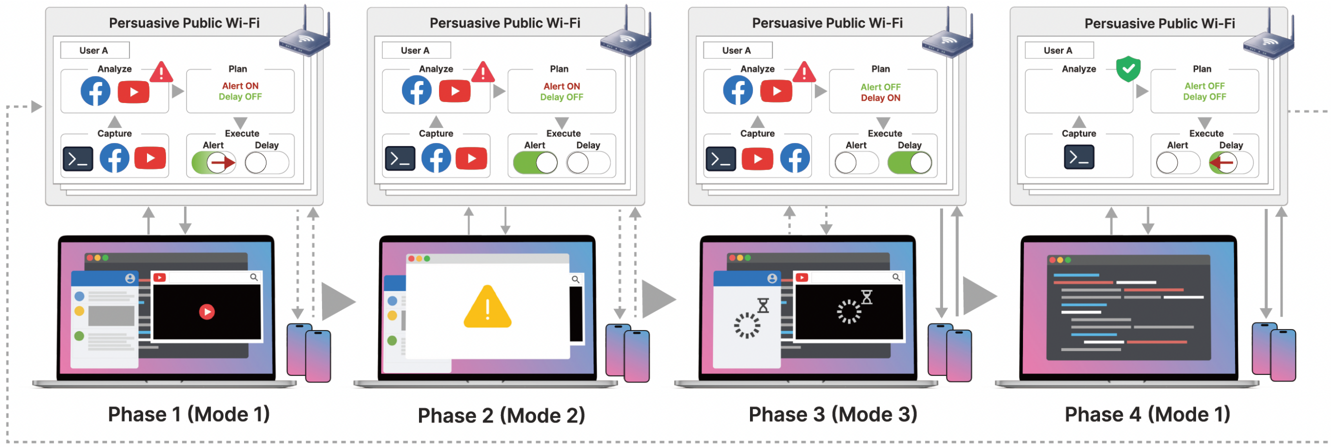


Fig. 3: Scenario Overview

TABLE I: A Part of Detected Protocols

Protocol	Packets	Bytes	Flows
Yahoo	1383	914528	35
Facebook	148	103454	10
Twitter	5990	6613286	38
YouTube	32047	35533417	16
WhatsApp	30	3498	1
Apple iCloud	31	13579	1
Apple iTunes	1018	473104	31
Instagram	15253	17458995	24
Line	521	278154	19
Tver	34529	40891719	45

services with nDPI (ntop Deep Packet Inspection) provided by ntop company. In fact, a part of the protocols identified by nDPI from several minutes of PCAP files is shown below. Furthermore, by adding domain-based rules to the nDPI configuration file, it was confirmed that content (Tver), which could not be identified by default, became identifiable. Such analysis are performed for each IP address, and the results are stored in a database to be used when intervening with individual users.

B. Warning Displays Based on Usage

With Pfsense, after network users authenticate, they can be directed to a website set by the administrator. For example, in this system, it is possible not only to display a warning screen through the captive portal that prompts users to interrupt their use of digital content (Figure 4 Pattern 1) but also to implement an intervention that makes users aware of their control over bandwidth (Figure 4 Pattern 2). This provides users with a choice to weigh the continuous use of bandwidth and digital content, enabling them to voluntarily perform prosocial behavior that can improve the overall network QoE.

C. Management of QoS Control

Vyos that performs QoS control can set the minimum and maximum downlink bandwidth for each IP address, and these can be configured using the command line provided by Vyos. The actual results of limiting the bandwidth for one of

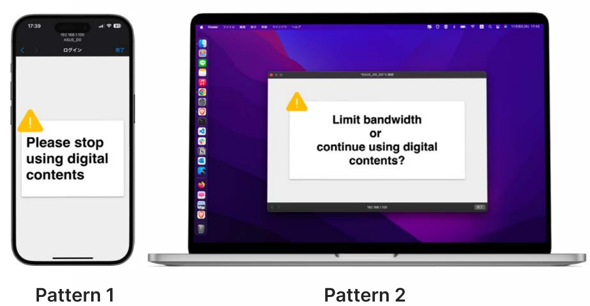


Fig. 4: Intervention via Captive Portal

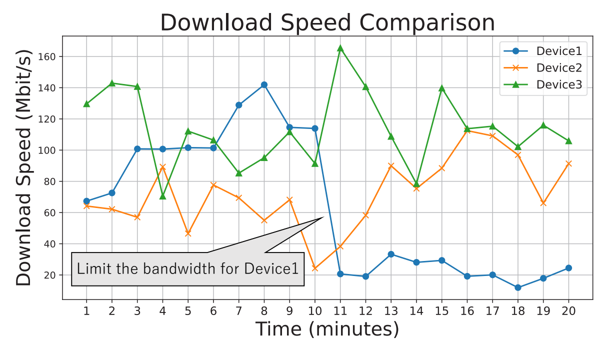


Fig. 5: Communication Speed by Device

three devices connected to the system are shown in Figure 5. After 10 minutes of connection, the minimum and maximum bandwidth were set to 20Mbit/s for Device1 based on actual measurements. As a result, a decrease in the download speed for only Device 1 was confirmed. Furthermore, while Device 2 initially showed a lower download speed compared to the other two devices, after implementing the bandwidth restriction on

Device 1, an improvement in download speed was observed for Device 2. This suggests that by restricting the bandwidth of devices that use a large amount of bandwidth, the communication speed of other devices can improve, potentially enhancing the QoE for other network users. Thus, even in a multi-device environment, it is possible to control the bandwidth for a single device, and the QoE provided can be intentionally varied depending on the set bandwidth value.

V. Conclusion

In this paper, we proposed "Persuasive Public Wi-Fi," which is a system that incrementally intervenes to encourage prosocial behaviors among users with consideration for the overall network QoE using Wi-Fi. The system operates in three modes, and the warning content through the captive portal and bandwidth settings can be flexibly changed by the network administrators according to the context required by the users. We developed a prototype of the proposed system based on the system design and verified the operation of each function. As a result, we confirmed that each function operated to meet the system requirements using the technology used. In the future, we plan to conduct intervention experiments using this system and to verify user receptivity and the effectiveness of the interventions.

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